An Analog Baseband Chain for a UMTS Zero-IF Receiver in a 75 GHz SiGe BiCMOS Technology

Werner Schelmbauer[1], Harald Pretl[2], Linus Maurer[1], Bernd Adler[3], Robert Weigel[1,2], Richard Hagelauer[1,2] and Josef Fenk[3]

[1]Institute for Communications and Information Engineering, University of Linz, Austria

[2]DICE Danube Integrated Circuit Engineering, Linz, Austria

[3]Infineon Technologies, Munich, Germany

Abstract — A zero-IF receiver for UMTS realized by using an advanced 0.35 μm SiGe BiCMOS process with 75 GHz transit frequency is presented. The focal point is the analog baseband chain consisting of a low-noise buffer (LNB), a fully integrated channel selection filter, programmable gain amplifiers (PGA) and circuits to reduce the effects of DC-offsets. The whole chain is able to provide a voltage gain from -14 dB up to 50 dB in 1 dB steps and 43 dB adjacent channel selectivity. The total receiver current consumption for a supply voltage of 2.7 V is less than 45 mA, whereby the baseband chain consumes 15 mA.

1. Introduction

Despite the recent delay in the commercial introduction of the Universal Mobile Telecommunications System (UMTS) in Japan, hand-set manufacturers are demanding highly integrated radio transceivers. The small form-factors of the new mobile phones put stringent requirements on the printed-circuit board (PCB) area required for the implementation of the various radio-frequency (RF) functions, and result in even more stringent limits for the current consumption of the building blocks that are used in today's radio transceivers.

All the mentioned requirements (low current consumption, small area) can be fulfilled by mastering the zero-IF (or homodyne) receiver architecture. This architecture offers a higher degree of integration than the traditionally used heterodyne-architecture by integrating the channel-selection filters on-chip. By carefully balancing system design and circuit optimization and by using advanced processes like SiGe BiCMOS technologies a very low current consumption can be achieved. The presented integrated circuit has been manufactured in Infineon Technologies' B7HFc 0.35 μm SiGe BiCMOS production technology [1].

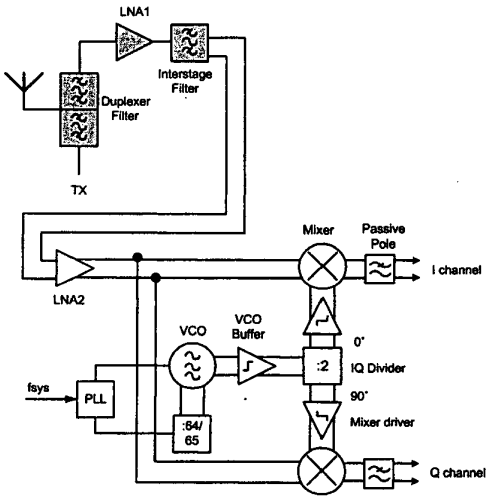

Figure 1: RF Front-end of the zero-IF receiver (the gray blocks are located offchip)

2. RF Front-End

Figure 1 shows the block diagram of the RF front-end. Although a high degree of integration is reached by using the zero-IF architecture, additional external building blocks are necessary. Without them it would be impossible to reach the noise

0-7803-7239-5/02/$10.00 © 2002 IEEE

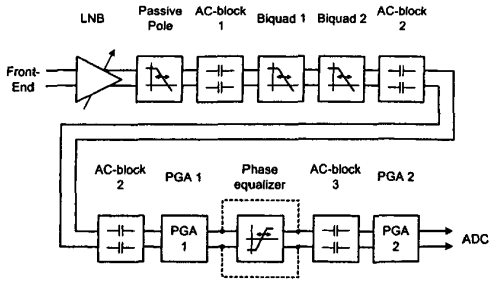

Figure 2: Block diagram of the complete baseband section (only one branch shown)

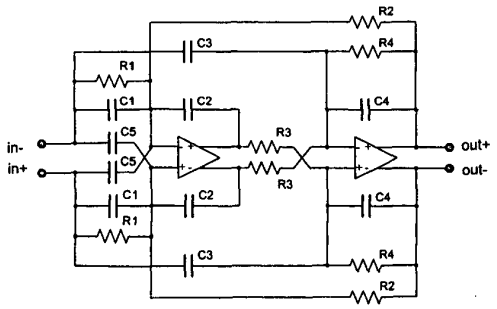

Figure 3: Tow-Thomas Biquad

and linearity requirements.

The first stage of the integrated receiver is a low-noise amplifier (LNA2). It is realized by using an inductive degenerated common-emitter stage. To provide a gain step, a selectable current shunting is implemented. The mixer is implemented as an improved BiCMOS Gilbert-cell type with differential input [2]. The mixer and the LO-driver are optimized for high IIP2 performance, as suggested in [3]. To get an accurate 90° phase shifted LO-signal, a master-slave flip-flop is used. Therefore the fully integrated voltage-controlled oscillator (VCO) has to run at double frequency, which also improves the LO-isolation. The VCO is controlled by an integer-N phase-locked loop (PLL).

3. BASEBAND CHAIN

The main tasks for the baseband chain are the attenuation of out-of-band signals and the alignment of the signal level to the dynamic range of the A/D-converter at the input of the digital baseband. Secondary it has to manage the main problem occurring in zero-IF receivers, namely DC-offsets. To keep the current consumption low and to observe the noise and linearity requirements, it is necessary to split the channel selection and the amplification into separate filter and separate gain stages. By interlocking the different stages a better optimization is possible [4]. Figure 2 shows the whole baseband chain.

The first stage in the baseband section is a low noise buffer (LNB). Because of the low gain of the RF front-end the noise requirements are very stringent. The LNB is able to provide five gain settings, which are realized bei five differently degenerated differential pairs which are connected to one common collector load.

The rest of the amplification is done by two identical programmable gain amplifiers (PGA) which provide 1 dB gain steps. The implementation is based on a R2R-network. Because of the superb matching characteristic of the R2R-network, 1 dB gain steps with an error less than 0.1 dB are achieved.

For the channel selection filter an optimized, i.e. previously unknown filter characteristic has been used. The pole- and zero-locations was found by an optimization algorithm, which was set up to achieve the optimum system performance (adjacent channel selectivity, amplitude ripple and phase ripple). It turned out that a lowpass filter of 6^{th} order with two passive poles and two biquads is the best solution. The two passive poles are located at the output of the mixer and the LNB. The poles are realized by using the output impedance of the mentioned stages, which causes no additional noise and improves the linearity performance. The circuit of the biquads is shown in figure 3. Additionally a phase equalizer was implemented to reduce the phase ripple. It is possible to bypass and power down the phase equalizer if the correction of the phase is not necessary or is done by the digital baseband. Due to

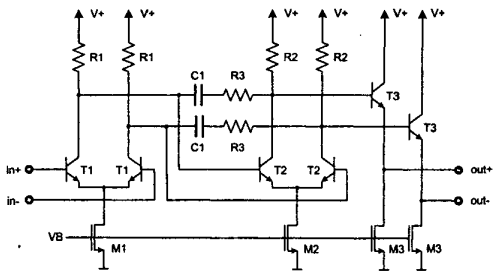

Figure 4: High speed operational amplifier

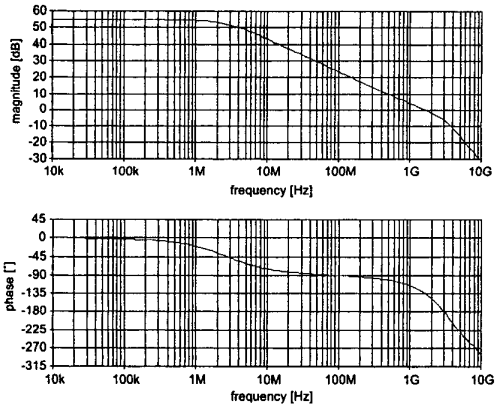

Figure 5: Simulated bode-diagram of the operational amplifier

the high quality factor of the poles combined with the high cut-off frequency (2.3 MHz), a very fast operational amplifier is needed [5]. Figure 4 shows the chosen circuit. It consists of two cascaded differential amplifiers and an emitter-follower as output stage. In comparison to other operational amplifiers, the impedance of the circuit nodes are much lower which causes a higher transit frequency. Figure 5 shows the simulated performance of the operational amplifier. To perform the system requirements, an error of the cut-off frequency lower than ±4% is an assumption. Due to the process tolerances of the resistors and the capacitors an error of up to ±30% is expected. Thus an automatic trimming circuit, which reduce the error to a maximum of ±4% was implemented.

Table 1: Measurement results of the baseband chain@ 2.7 V and 27°C.

Parameter	Measurement
IIP3 (10 MHz & 19 MHz, max. gain)	20.6 dBVrms
P1dB (inband, max. gain)	-50.5 dBVrms
Input noise density (inband, max. gain)	8.0 nV/$\sqrt{Hz}$
Filter 3 dB roll-off frequency	2.33 MHz
Amplitude ripple (inband)	< 0.7 dBpp
Phase ripple (inband)	< 4°pp
Integral attenuation (3.1 MHz - 6.9 MHz)	43 dB
Max. gain	48.5 dB
Min. gain	-15.5 dB
Gain step error	0.1 dB
Current consumption	14.43 mA

As mentioned above DC-offsets are one of the biggest challenges in zero-IF receivers. Because of the high gain in the baseband (up to 50 dB for this chip), even small DC-offsets are able to saturate the baseband chain. On the one hand it is necessary to minimize the sources of DC-offsets (IP2-effects, LO-leakage and component mismatch in the baseband chain), on the other hand it is inevitable to filter the offsets at proper locations in the baseband chain. A straight forward method to filter DC-offsets is the implementation of AC-couplings. System simulations have shown that a maximum 3 dB roll-off frequency of 10 kHz is allowed to have no influence to the system performance [6]. Unfortunately filters with such low cut-off frequencies have a long settling time. So the filter needs a long time to react to rapid changing offset conditions, which can occur if the gain in the baseband chain is changed. As a work around, adaptive AC-couplings are used for this chip.

4. Measurement Results

Table 1 shows the measured results of the baseband chain. The cut-off frequency is 2.33 MHz, which is equivalent to an error of 2 %. The reduced maximum gain is a consequence of the voltage divider between the separate building blocks.

In figure 6 the limits of the tuning range and the automatic trimmed frequency response of the channel filter is shown.

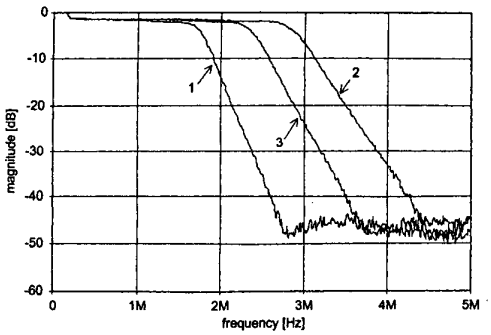

Figure 6: Frequency response of the receiver: lower limit (1) and upper limit (2) of the tuning range, automatic tuned response (3)

The comparison between conventional AC-coupling and adaptive AC-coupling is shown in figure 7. A 6 dB gain step at the LNB leads to a transient peak of more than 800 mV using the conventional AC-coupling. In contrast the measurement for the adaptive AC-coupling shows no visible DC-transient.

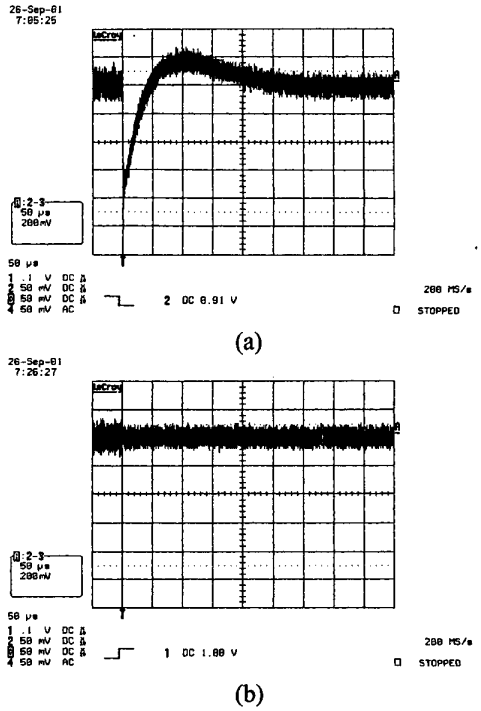

Figure 7: DC transient after gain step in LNB with conventional AC-coupling (a) and with adaptive AC-coupling (b)

5. Conclusion

The achieved results for this IC shows that it is possible to solve the problems occurring in the baseband chain of a zero-IF receiver. Relating to the bill of material the zero-IF architecture is the optimal solution. With regard to the current consumption it is a tough task to achieve a better result than well designed heterodyne receivers.

Acknowledgement

The authors would like to acknowledge the following contributors to this design: H.-P. Fuchs, T. Greifeneder, B. Heigelmayer, C. Stöger, A. Schwarz, G. Eschlböck, and D. Pimingsdorfer, DICE, and V. Thomas, U. Klepser and M. Scholz, Infineon Technologies. Special thanks go to the layout team for the excellent work.

References

[1] W. Klein, A. Müller, and K.-R. Schön, "General specification B7HFC," Tech. Rep., Infineon Technologies, 2000.

[2] J. Jussila, J. Ryynänen, K. Kivekäs, L. Sumanen, A. Pärssinen, and K. Halonen, "A 22mA 3.7dB NF direct conversion receiver for 3G WCDMA," in *IEEE Proceedings International Solid-State Circuits Conference*, 2001, pp. 284–285.

[3] H. Pretl, "SiGe RFIC zero-IF receiver frontends designed for 3GPP applications," in *Workshop RF System and Circuit Issues of Third Generation Wideband CDMA Systems Like UMTS*. IEEE Proceedings International Microwave Symp., 2001.

[4] W. Schelmbauer, H. Pretl, L. Maurer, R. Weigel, B. Adler, and J. Fenk, "A fully integrated analog baseband IC for an UMTS zero-IF receiver," in *Proceedings AustroChip*, 2000, pp. 8–15.

[5] W. Schelmbauer, L. Maurer, H. Pretl, B. Adler, and R. Weigel, "A fully integrated continuous-time channel selection filter for a UMTS zero-IF receiver," in *ITG-Fachbericht Mikroelektronik für die Informationstechnik*, 2000, pp. 61–65.

[6] J. H. Mikkelsen, T. E. Kolding, T. Larsen, T. Klingenbrunn, K. I. Pedersen, and P. Mogensen, "Feasibility study of DC offset filtering for UTRA-FDD/WCDMA direct-conversion receiver," in *Proceedings 17th NORCHIP Conference*, 1999, pp. 34–39.